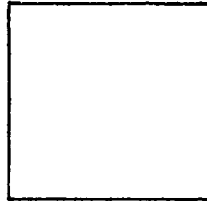


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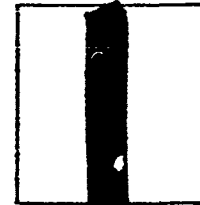
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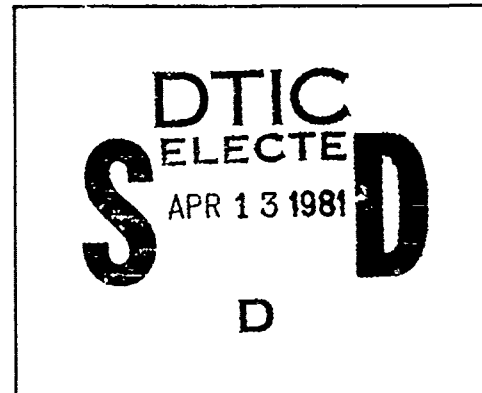
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Annual Report
Development & Research Activities
Fiscal Year 1935

The following subjects are covered herein in the order listed.

- 1 - Centrifugal Casting
- 2 - Welding
- 3 - Armor Plate
- 4 - Non-metallic Elements
- 5 - Corrosion
- 6 - Corrosion Resisting Materials
- 7 - Erosion
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- 14 - Physical Properties of Materials
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19 - Activities with Technical Societies

20 - Organization

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22 - List of Laboratory Reports distributed.

CENTRIFUGAL CASTINGS

1. Induction Furnace Practice.

The all wooden furnace construction has proven to be highly successful for small sizes. The 120-lb. furnace built at the end of the past fiscal year has melted and poured about 400 heats on two linings, one acid and one basic. Of these, 375 were 18-8 stainless centrifugally cast by the foundry at the U. S. Navy Yard, Charlestown, Mass. A new magnesia lining has been installed without the need for any repair work whatsoever on the coil or the furnace proper. Since commercial furnaces of this type are usually entirely rebuilt after 300-500 heats, this is very gratifying. The 120-lb. furnace draws 75 Kilowatts at 800 Volts and melts 120 lbs. of steel in about 30 minutes. A furnace to draw 100 Kilowatts at 800 Volts to melt 300 lbs. of steel in about 45 minutes has been built of all wooden construction. This furnace has melted and poured about sixty heats without trouble. The cost of these furnaces was \$28.00 and \$36.00 respectively for labor and materials.

Acid linings are still put in as described in the previous annual report. For the preparation of 18-8 stainless steel, a basic lining was considered desirable. A mixture of 90% electrically cindered magnesite and 10% RM 868 (a magnesia cement manufactured by the Norton Co.)

lightly tempered with water was installed exactly as the acid linings are installed. The first lining gave 375 heats without cracking or other trouble. On removal, it was in perfect condition. The cost of materials and labor to install this lining was \$3.75. The cost of a magnesia crucible for a similar furnace is \$12.50. 150 heats is excellent life for a preformed magnesia crucible. This indicates that good basic linings can be installed without use of the preformed crucible.

After some careful experimentation, entirely on production or laboratory heats, the use of a slag composed of equal parts of red clay, dry lime and cryolite has become standard. This is used entirely as a finishing slag on acid-lined furnaces: the highly siliceous melting slag being removed before its application. Samples of this slag taken from ladles and runner boxes after pouring the heat analyse approximately as follows:

FeO	5%	MnO	15%
CuO	2%	Al ₂ O ₃	9%
SiO ₂	45%	Compounds containing	
		Na	24%

With this slag, charges averaging 0.025% Sulphur are giving 0.015% Sulphur after pouring.

With basic linings now available in addition to acid linings, and with the encouraging results obtained, proper research into the possibility of preparing superior quality steel in the high frequency furnace appears highly desirable.

2. Study of Metals.

A total of 133 castings have been poured from the 60-lb. and 120-lb. furnaces into the model casting machine. These have been of a wide variety of metals: various alloy steels of gun forging, engineering and stainless grades; bronze and a variety of copper-nickel alloys.

The gun forging steels have been cast and tested with two viewpoints in mind:

- a. To improve the ductility figures obtainable in metal having strength characteristics as now required.
- b. To obtain high strength figures without falling below existing gun forging ductility limits.

The elimination of the lustrous cavity imposed the condition that carbon should be down to 0.30% or under. The results of these investigations may be summarized as follows:

- a. With Carbon between 0.20% and 0.30%, castings can be made with a Proportional Limit between 75,000 and 80,000 lbs. per sq. in., a Tensile Strength between 95,000 and 100,000 lbs. per sq. in., with Elongation over 25%, Reduction of Area over 65% and Charpy over 40 ft. lbs. This may be obtained with simple steels such as 0.30% Molybdenum, 1.5% Nickel, 0.10% Vanadium; 0.50% Molybdenum, 0.10% Vanadium;

1.0% Molybdenum, 0.10% Vanadium. There are indications that 1.5% Copper is more valuable than 1.5% Nickel.

With Carbon between 0.10% and 0.20%, castings can be made with a Proportional Limit between 75,000 and 90,000 lbs. per sq. in., a Tensile Strength of over 100,000 lbs. per sq. in., with Elongation over 25%, Reduction of Area over 65%, and Charpy over 45 ft. lbs. This may be obtained with simple steels such as 0.50% Molybdenum, 2.5% Manganese.

b. A Proportional Limit of over 110,000 lbs. per sq. in., with a Tensile Strength of over 125,000 lbs. per sq. in. may be obtained with Elongation over 18%, Reduction of Area over 45% and Charpy over 25 ft. lbs. These results can be obtained with the various steels mentioned in a above with proper heat treatment.

The results were obtained from transverse bars taken midwall in castings having an Outside Diameter of 5-3/4" and an Inside Diameter of 1-1/2".

The heat treatment of the standard composition is fairly well understood. It becomes increasingly evident that preparation of steels to far exceed existing gun forging specifications requires a complete knowledge of heat treatment operations. Thus, it has been established that the 1150°C 28-hour normalizing treatment given the

standard composition, has little effect on a Chromium-Nickel-Molybdenum composition. With proper heat treatment, the latter steel should produce superlative results. Development of the heat treatment practice along with the melting and casting practice demands their control by a single individual. Insufficient personnel has prevented this, and has provided a serious handicap to proper pursuit of the work.

Application of the results of this research has been made to guns falling into two classes:

a. Specification:

<u>P. L.</u>	<u>T. S.</u>	<u>Elong.</u>	<u>Red.</u>
95,000	115,000	18%	30%
(U.S.Navy - 191 MG MK1 - not cold worked)			

Composition

C	.25/.35	S and P	<0.02
Mn	.90/1.10	Mo	.45/.55
Si	.15/.25	Va	0.10

Final draw temperature - 655°C.

This has met the specification with Elongation 20% and Reduction of Area 55%.

b. Specification:

<u>P. L.</u>	<u>T. S.</u>	<u>Elong.</u>	<u>Red.</u>	<u>Charpy</u>
65,000	95,000	18%	30%	24 ft. lbs.

Composition

C	.20/.30	S and P	<0.02
Mn	.60/.80	Mo	.45/.55
Si	.15/.25	Va	0.10

Final draw temperature - 690°C.

This has been giving:

<u>P. L.</u>	<u>T. S.</u>	<u>Elong.</u>	<u>Red.</u>	<u>Charpy</u>
80,000	98,000	24%	60%	35 ft.lbs.

on 75 mm. Pack Howitzers.

Trouble has been experienced with flakes due to insufficient knowledge of heat treatment, especially with the .10/.20 Carbon, 0.50% Molybdenum, 2.5% Manganese, which offers superb possibilities.

3. Development of Equipment

The design of the casting for the 1.1 MG MK1 USN called for a mold of complicated internal shape. The boring of this hole in the heavy solid mold presented great difficulty and was a very expensive operation. Since the design of one-piece guns calls for a heavy chamber and breech section with a comparatively slender tapering tube, it is expected complicated mold shapes will be the rule. Moreover, it seems probable that curves will come back as external gun

shapes which will be made from one-piece castings.

The model casting machine has been cut in half to permit making castings up to 6" in diameter and a maximum of 50" long. The new air-cooled machine is completed and installed in Building 41, ready to operate when the removal of the plant is completed. It seemed logical to attempt to cast the thin-walled molds with the hole cast ready to use. This involved developing a foundry technique in making molds and cores which could be used for this purpose. A limit of $\pm 0.01"$ was taken for straightness and roundness with $\pm 0.10"$ for dimension. Cores were rammed up in especially constructed core boxes on especially machined arbors. These arbors were suspended in the core boxes, drawn vertically, turned vertically to true up the core, dried, suspended in the mold on a vertical machined pin and poured with complicated gating. After several attempts and failures, two thin molds, one cylindrical and one tapered, were cast which fell within the tolerances prescribed. Considerable work remains to be done to perfect the method for producing longer molds. Ultimate results in cost of molds, mold life, and rapidity of manufacture are believed to justify the work.

The use of artificial cooling is definitely successful for small sizes. Maintenance of an outer mold surface temperature of 500-600°C produces a chill that is equivalent to that produced by the heavy molds in the older machines.

This can be done by blowing air at 100 lbs. per sq. in. through 7 holes $3/32$ " in diameter on the rotating cast iron mold having an Inside Diameter of 5.75", an Outside Diameter of 7.1" and a length of 1". This figure varies directly with the diameter of the mold. The possibility of super-chilling the steel by use of more air and molds of higher conductivity than cast iron is very inviting.

A second great advantage developed by the air-cooled machine is the possibility of operation over extended periods of time without having to suspend operations to cool the machine. Castings have been poured at an average rate of 1 every 30 minutes for as long as 6 hours without any sign of over-heating.

The first attempt to pour castings of complicated shape occurred last year with the double taper tube mold. Experience with the 1 $\frac{1}{2}$ " MG mold, which has five tapers, indicates that the single taper limitation is definitely overcome. With ample fillets and no steep tapers, no trouble is experienced. This renders all of the molds on hand (except the 1 $\frac{1}{2}$ " MG) obsolete.

Several minor changes have been made in the equipment. Most important of these are installation of an oil filter and development of a new spout gage. The former obviates the necessity for throwing away oil after one use. The latter has facilitated spout adjustment. The only major

difficulty experienced in the casting operation is due to the fact that the furnace, pouring device and runner box form a single unit moving on a track. When the plant is moved to Building 41, a new design which has been completed will be used. The pouring device is permanently installed. The runner box sets on ways permanently established forward of the machine with only enough movement to permit of spout insertion.

Development of a few other minor improvements in detail is covered in Experimental Report No. 385, Watertown Arsenal.

4. Development of the Process.

Using the model machine, castings have been made of various stainless steels, bronze and a variety of copper-nickel alloys. These experiments were based on enlarging the scope of the process to include the casting of thin-walled castings for recoil and recuperator cylinders. The bronze castings were utter failures due entirely to poor quality metal. The stainless steels proved excellent and are undergoing thorough investigation.

Several full-size castings have been made with uniform success. The question as to the value of the material for recoil cylinders has not yet been settled. The monel experiments were a repetition of those done last year. Information was received from the International Nickel Co.

that the pig metal supplied was of poor grade. Accordingly, they furnished new material and a supply of alloys, deoxidizers, etc., for a repetition of the experiments under the guidance of Mr. Kayes of the Company.

The castings were successful this year--especially the K Monel. As cast bars, cut transversely from the centrifugal castings, have properties as high as 44% Elongation with 83,500 lbs. per sq. in. Tensile Strength, and, after thermal treatment, 35.7% Elongation with 102,500 lbs. per sq. in. Tensile Strength. These results are encouraging and open up a field for development. Molds have been designed for all recoil and recuperator cylinders but none have as yet been obtained. A good melting practice has been acquired, thanks to the excellent instruction of Mr. Kayes.

The most important development of the process was the attempt to run at something near to capacity over a period of one month. In December, 1934, 93 centrifugal castings were cast with only 3 rejections in the foundry. The plant operated 5 days per week, 8 hours per day. Plans called for 7 castings per day, 4 days per week. This schedule was met using a total of seven men including supervision. This included manufacture of all seals, spouts and fittings at a rate ample to insure continued production. No trouble was experienced in maintaining the schedule.

WELDING

The experimental welding program for the past year has been primarily concerned with the welding of alloy steel plates of 1/2" and greater thicknesses and the repair of steel castings. Considerable welding of stainless steel castings for the Navy Wet Mounts has been effected without any preliminary experimental welding program.

Laboratory Reports Nos. 642/70 and P642/76 were prepared covering the work done on three grades of 1/2" structural nickel steel plate. This work was promoted by the need for a commercially obtainable alloy steel electrode suitable for welding 1/2" nickel steel plate and heavier to obtain full plate strength across the welded joint. Tensile strengths of better than 100,000 lbs. per sq. in., with an elongation of 18% across the weld and a tensile impact strength of 600 ft. lbs. were obtained with a nickel-molybdenum electrode in the "flat" position. A need for a suitable "position" type alloy steel electrode appears to exist, as none of those tested appear to be of this type.

A preliminary study is being made of several structural molybdenum alloys, one of which has a tensile strength of 100,000 lbs. per sq. in., and all appear to be easily weldable. One significant difference between these molybdenum alloys and the structural nickel is their freedom from air hardening alongside the weld in the heat affected zone. Test data on

weld strengths on the molybdenum plate are not yet available so that comparisons of strength cannot be made at this time.

It is believed possible that a suitable high tensile structural alloy steel can and will eventually be developed which will be amply sufficient for Ordnance engineering purposes and not affected by the heat of welding to any appreciable degree.

The results of a detailed study of the heat effect of welding on the parent metal adjacent to the weld are given in Report No. 640/27, which is a thesis submitted in the Harvard University School of Metallurgy toward the degree of Doctor of Science in Metallurgy by Mr. W. G. Theisinger with whom the Arsenal has cooperated in carrying on the work. The results of this study should be of interest to anyone concerned with the application of welding as comparisons of heat effect are given for plain carbon steel (0.17% C-0.53% C), chrome-molybdenum steel (0.33% C and 0.52% C), three structural nickel steels and two structural molybdenum steels. Apparently, little thought has been given to the question of the heat effect of welding by those concerned with the development of high tensile steels.

Some studies of the effect of a 600°C stress relieving treatment on welded joints on thin structural nickel plate (1/4" and under) have indicated a considerable change in the heat affected zones adjacent to the welds and a considerable increase in the strength of the joints under dynamic loading.

Tests made on structural carbon steel by various industrial concerns have not shown similar changes due to stress relieving so that one might assume the difference to be due entirely to the different characteristics of the two classes of plate material or to the different methods of testing the welded joints.

In order to obtain information on this point, an investigation of the effect of stress relieving butt joints on 3/4" plate, welded with bare and covered low carbon electrodes of commercial types, was conducted. Both structural carbon and nickel steel plate were used. The results have not yet been prepared as a laboratory report because it is planned to conduct a check test on the nickel plate, using a suitable alloy steel electrode and it is believed desirable to report all at one time.

Two types of tensile test specimen and three types of impact specimen were used in testing the welds. Effects of the heat treatment observed were a slight reduction in ultimate tensile strength with a slight increase of elongation across the weld. The proportional limit was reduced about 5,000 lbs. per sq. in. in the weld metal and the joint itself. There was no noticeable change in the impact results due to the heat treatment.

With the covered electrode, the proportional limit of the joint was approximately 50,000 lbs. per sq. in. on the

nickel plate and 40,000 lbs. per sq. in. on the carbon plate. The proportional limit of the weld metal was approximately 55,000 lbs. per sq. in. on both plates. This characteristic of the weld metal seems rather remarkable when it is realized that the carbon content is only about 0.12%. It is difficult to imagine a cast steel of this carbon content possessing physical characteristics as described here.

A hardness survey of the weld cross-sections and heat affected zones showed maximum hardnesses as follows:

<u>Plate</u>	<u>As Welded</u>	<u>Stress Relieved</u>
Carbon	209	181
Nickel	437	246

These figures are isolated maxima and occur generally in the heat affected zone of the seal bead. These average hardnesses of the heat affected zones are lower than would be the case with a single layer weld on thin sheet. Hence, stress relieving does not show the same change of impact strength.

The strength developed by a butt joint welded with a certain electrode is not necessarily indicative that suitable fillet welded joints can be obtained with that electrode on the same grade of plate material. In order to obtain design data on the strength of fillet welds on structural nickel steel plate of 3/8" to 1" in thickness, considerable preliminary work has been done in making up welded specimens with bare and covered low carbon electrode. Alloy steel electrodes

have not been included because a suitable electrode of that kind for structural work has not been obtainable. It was decided to test the possibilities of using commercially obtainable low carbon electrodes and determine the strengths which could be developed with this class of electrode so that this data could be used as a basis for later selection of a suitable alloy steel electrode.

It was found impossible to make a fillet weld on 1/2" and 3/4" thick nickel steel plate which would be free from cracks except with bare electrode and three brands of covered low carbon electrode, all three of which were of the "position" type. The half dozen or so alloy steel electrodes of the "flat" type which were tried gave cracked welds. These tests have not been completed, but it is believed that the test procedure used to check electrodes for making fillet welds on heavy nickel steel plate can be made of practical use for checking electrodes and avoid unnecessary machine work and testing of undesirable electrodes.

The program of manufacture of the castings for the Navy 5" 38 Cal. A. A. gun mount necessitated the repair of cracks in castings which had been finish-machined. Considerable experimental work was required to determine the best method of procedure, and three castings were welded before the details had been worked out. The results of this work are described by Laboratory Reports Nos. 647/2 and 647/3, together with recommendations as to repair of similar castings

in the future.

A study of weld failures in base plates of 81 mm. Trench Mortars was made for Watervliet Arsenal and welding instruction was given to a welder and an inspector from that Arsenal. Report No. 642.1/27 covers the results of the examination of weld fractures on the base plates.

Tentative Welding Specification WXS-31 was revised and compiled in accordance with arrangement suggested by the Ordnance Office. Copies of this specification have been distributed to the industry for criticism. The comment which has been received has been mostly favorable and constructive, but has not yet been incorporated. This specification limits the carbon content of nickel steel plate for welding to 0.35%.

Work was started on a specification for electrodes modeled somewhat after that of the Navy which sets up an Approved List of electrodes, admittance to which is obtained on the basis of electrode qualification tests made at the manufacturer's expense. This Approved List requires certain standards of performance which are desirable, but has the disadvantage of a certain lack of control afforded the welding organization as the number of different commercial electrodes available gain entrance to the list. It usually is more satisfactory for the user to buy electrodes in small lots to avoid open bidding and obtain the type of electrode to which the welding organization is accustomed. It is also possible to juggle the performance value of an electrode on the Approved List in

order to insure obtaining that electrode on competitive bidding schedules. It is believed to be impossible to successfully draft an electrode specification which will insure one brand of electrode being obtained on all orders for use in the welding shop.

ARMOR PLATE

A comprehensive program has been carried forward in an effort to increase the ballistic efficiency of light armor for protective plating. It may logically be divided into three phases: - (a) intensive study of existing plate and of current manufacturing practices; (b) the development of better plate compositions, of improved methods of heat treatment and of new types of plate; and (c) cooperative study and investigation of armor plate projects submitted by interested civilian agencies.

Metallurgical investigation of representative types of plates tested at the Aberdeen Proving Ground has been continued in order to find, if possible, some relation between the metallurgical characteristics and the ballistic efficiency of plates, and to obtain information on the mechanism of penetration.

Microscopic evidence and hardness surveys indicate to some extent the magnitude of permanent deformation under the impact of armor piercing bullets. Measurement of the total affected volume of metal participating in the transfer of energy from bullet to plate may be possible with some additional study. Such measurement should open the way for a rational mathematical solution of this fundamental problem.

Studies of the microstructure of similar plates with widely different ballistic properties has been attempted.

The results obtained thus far are not conclusive. Considerable data is being amassed, however, and definite information should be forthcoming in the next year or two.

Surveys of the hardness of successful ballistic samples have shown a much greater variation than was expected. The results obtained may show why it has not, as yet, been found possible to establish a fair relation between hardness and the ballistic efficiency of light plate.

The use of the impact test at several of the very low velocities has established beyond doubt that the capacity of any two metals to absorb energy may vary markedly with the velocity of impact. Development of the high speed impact testing machine should open a wide field for the study of the behavior of various armor plate steels at higher velocities and it is expected that the results of such work will be extremely important in armor plate development.

Some data concerning the various commercial manufacturing practices have been obtained. Steps have been taken to make full use of the current orders for armor plate in obtaining more of this valuable information.

Various types of composite plates comprising layers of homogeneous armor, soft steel and aluminum have been developed. Such plates have proved to be effective in stopping super-velocity soft bullets, such as the Gerlich, and equal to the same weight of solid plate in resistance to armor piercing bullets.

Another mechanical means of increasing ballistic efficiency has been undertaken in the preparation of fluted or grooved plates. An important increase in efficiency was obtained with grooved homogeneous plates. Samples tested at the Aberdeen Proving Ground developed ballistic limits from 10% to 50% higher than the best flat plates of the same composition that have ever been tested at the Proving Ground. In addition, one of the grooved plates, with a weight equivalent to that of 7/16" flat plate, defeated the T1 (High Velocity) A. P. ammunition.

Forty 60-lb. ingots of promising steel compositions were made, forged into bars, and tested in comparison with the usual 0.50% carbon homogeneous Chromium-Molybdenum-Vanadium steel. Tension and impact test results indicate that some five or six of these steels may offer an improvement in homogeneous plate. Additional small ingots of these compositions will be rolled into plate for ballistic test.

Studies were made of the effect of various preliminary heat treatments on homogeneous 0.50% carbon Chromium-Molybdenum-Vanadium plate. The results indicated that the present heat treatment (oil quench 1600°F Draw 1100°F) develops the maximum ballistic resistance and that variation of the preliminary treatment by high temperature normalizing, double and triple-quenching, etc., does not improve the ability of the plate to withstand armor piercing ammunition.

The Navy Department encountered difficulty with special

treatment steel for protective plates. Some of their plates shattered when tested at low temperatures. In a cooperative program, a special Charpy impact test was developed at this arsenal to pick out plates with this defect. As a result of this program, this arsenal is now making similar tests on all acceptance test plates ordered by the Navy Department.

About twenty short programs were carried out on samples submitted by interested civilian agencies to the Ordnance Office and to this arsenal. These programs involved (a) methods of applying hard faces to plate, (b) multiple layer plates, (c) proposed types of bullet resisting alloys, etc.

NON-METALLIC ELEMENTS

Centrifugally cast guns contain large amounts of non-metallic elements in various ranges of size. Contemporary work and opinions of recognized metallurgists have indicated that while large "inclusions" appear to have no detrimental influence on steel, the smallest particles probably play a very definite role in determining either the good or bad qualities of the metal in which they occur. The program for this section of the laboratory was a microscopic investigation of the effect of heat treatment on all particles of non-metallic elements in centrifugal castings, focussing particular attention on the finest ones, and a correlation of this data with physical properties.

It was planned to utilize the ultimate resolution of our optical system in order to make a thorough study of material in the lowest size range. Initial visual inspection and photographing of the unetched metal surfaces at 3500 diameters revealed that the preparation of the specimen was unsuitable. The fine objective brought into view scratches which had been invisible at lower magnifications, which definitely obscured the presence of minute included matter and which gave the entire area a rather rough appearance. Although this type of polish had been satisfactory for previous work on metallographic structures, it was now evident that etching must have obliterated any objectionable conditions and that the technique would have to be greatly refined before dependable examinations of unetched specimens

would be possible. It was essential, therefore, to make a preliminary study of metallographic polishing before proceeding with the problem of non-metallic elements.

A survey of all available publications on the subjects of the theory and technique of metallographic polishing revealed that the procedures differ widely in details but not greatly in essentials and led to the conclusion that a properly polished surface, in a large measure, is dependent upon the person who produces it.

Meanwhile, as a result of experimental work, a decided improvement in the quality of our finished specimens was accomplished. This was due, not to the development of a new technique, but to the following:

1. The adoption of suggestions contained in several of the writings which had been analyzed.
2. The relevation of our abrasives to a very fine size.
3. The development of increased skill in handling samples.
4. A constant microscopic check on the metal through each step of the polishing process, noting carefully the condition of the included matter and the depth and number of the scratches. Inspection was made both at low and at high magnification

using ordinary as well as dark-field illumination. Special equipment for the latter was purchased for this purpose.

Verification of the advance made in our own technique was effected by examining the polishing done by others. A bar taken from a disc which had been sliced from a centrifugal casting was cut into several pieces. Three of these were given a metallographic preparation in laboratories which have been outstanding because of their work on polishing, viz. Bell Telephone Laboratories, Union Carbon and Carbide Laboratory and the Laboratory of Economic Geology at Harvard University. A fourth specimen from the same bar was polished at Watertown. Comparison of the four surfaces showed the definite, superior quality of the work produced here. It is best shown by means of illustrations which will be included in an experimental report.

Although it is intended to aim constantly at an even greater and necessary improvement in our polishing practice, the present technique has been developed to such a point that the original problem - the study of the effect of heat treatment on non-metallic elements - may now progress.

CORROSION

Report No. 742/5, "Corrosion of 3" A.A. Gun Mount M2 #5" was completed and distributed. Corrosion was found to have occurred in this gun mount which had been submerged for 12 hours and left wet for 2 more days. The corrosion was for the most part associated with metallic couples. Steel parts in the vicinity of bronze were rusted. The grease that was used for lubricating purposes after the storm, but before inspection was found to be highly acidic at time of inspection. Corrosion was found in the monel cylinders of the equilibrator. This was attributed to pick up of some dirt or particles of noble metals as silver or copper and setting up galvanic acid.

Metallic combinations may be unserviceable from wear point of view and from point of view of corrosion. The properties of K Monel were discussed last year. An application required K Monel to rub upon itself. Galling occurred. One of the rubbing members must be replaced with another metal. Bronze was found not to gall even if unlubricated. Tinning or cadmium plating one of the K Monel surfaces is another method of substituting a different metal on the rubbing surface. Both prevent galling temporarily. Wear of tin is such that galling

occurs eventually. Cadmium plate tends to flake off readily. Diffused soft solder and silver solder prevent galling satisfactorily only if lubricated. (Reports 344/24 and 344/24-1).

When metallic combinations are immersed in electrolytes, galvanic cells are set up which may cause extensive corrosion. Study revealed that 18/8 stainless alloy is cathodic to monel, unless secondary effects occur, inconel, bronze, hardened stainless steel, chromium, tin, stainless iron, solder. Stainless iron is anodic or corroded by chromium, monel, inconel, bronze, but is cathodic to tin. Non desirable combinations are those capable of maintaining a current of more than 0.003 ma/sq.in. through a resistance of 540 ohms. Bronze with monel or 18/8 stainless steel or 18/2 stainless alloy or 17% Cr stainless alloy, monel with 18/8 and inconel with 18/8 are probably safe combinations in weak electrolytes. (Report 780/1).

This arsenal has studied joints of 18/8 that had been made by acetylene gas and by hydrogen welding. The gas weld had picked up so much carbon that the carbides formed a continuous network around the grain boundaries. They could not be removed by heat treatment. The weld had poor corrosion resistance. The hydrogen welded metal however did not pick up carbon and the

weld was very inconspicuous. Heat treatment redissolves the precipitated carbides in the heat affected zone and removed the cast structure of the weld so that it was very difficult to differentiate weld metal from plate metal when examined at high magnification.

CORROSION RESISTING MATERIALS

A study of the so-called low chromium 46 semi-stainless steel revealed that when exposed to the atmosphere or to salt spray rust appears equally as fast as on ordinary steels. The alloy possesses moderate properties and excellent ductility and impact resistance. (Report W. A. 316/25).

The possibility of improving the wearing properties of 18/8 stainless steel by adding lower quantities of Selenium than usual was investigated. Low Selenium 18/8 stainless steel was found inferior to Monel Metal for piston rods. By inference it will not be suitable for recoil cylinders. The presence of only 0.1% Selenium in 18/8 has slight effect, if any, on transverse impact properties but has a slight effect upon transverse ductility, (Report W.A. 316/24).

The use of resistal 2 carbon which is a high Silicon 18/8 composition as a direct substitute for steels for piston rods was investigated. After following manufacturer's

recommendations for forging and annealing, the physical properties were found to be too low. This material could not be considered as suitable for the purpose intended. (Report W.A. 316/23).

A study is in progress of the properties of stainless alloys containing 16-20% chromium and 1 - 3% Nickel. This alloy is amenable to heat treatment and possesses good ductility and impact properties. Proportional limits between 45,000 p.s.i. and 110,000 p.s.i. are obtainable. The alloy is apparently superior in corrosion resistance to stainless iron but is not as good as 18/8. It is cathodic to (protected by) bronzes and for that reason is considered better than stainless iron for ordnance purposes (Report 316/22).

As a result of a rather extended study, it was concluded that zinc base die castings containing 3.5/4.3% aluminum; 0.03/0.08% Magnesium and balance high purity zinc appear suitable for ordnance purposes requiring many duplicate parts whose dimensional tolerances are nominal and whose dimensions are not large. To improve the corrosion resistance a dichromate film, applied by dipping, appears satisfactory. Other compositions are available, but they usually contain copper which increases the tensile properties but which accelerates the ageing and the dimensional changes

which accompany the ageing. A specification (WXS 8) has been written around the composition considered most satisfactory. (Report W.A. 671/1)

An investigation of the properties of sand cast Monel Metal and some of its newer modifications revealed that the surface of regular Monel sand castings is better than the surface of Silicon Monel Castings. The physical properties of the castings submitted (and not of cast test bars) were variable and in general were lower than called for by specification. The addition of 2 1/2% Silicon increased hardness slightly, decreased ductility and impact. The addition of 3 3/4% Silicon increased hardness and tensile strength materially, and decreased machinability, ductility and impact to very low values.

Cylinders of stainless iron can be successfully centrifugally cast. Heat treatment, to obtain suitable properties is not as straight forward as it appears. One casting that was studied after having been given the usual heat treatment was found to be non homogeneous in structure, containing much delta iron. The corrosion resistance was not satisfactory. Refinements in heat treatment are necessary. (Report W.A. 314/457).

Several new bronzes have appeared on the market. Samples of some have been obtained for study which has not been completed yet.

A study of increased Magnesium Monel Metal is under way. The metal is being used for guns. Tensile strengths are quite high as 120,000 lbs. per square inch for 8" forging, with good ductility. These properties are obtained by cold working. Investigation of the ability of this metal to absorb energy at various speeds is being carried out.

Corrosion in recuperator mechanisms using glycerine solutions is now being studied under service conditions. Rock Island Arsenal has 155 mm Howitzers in storage and this arsenal has 12" mortars. The correctness of laboratory detail will be checked before further development work is undertaken.

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EROSION

In measuring wall temperature of a gun during firing, a maximum temperature observed was 485°C at a point 0.077" from surface of bore and in front of the origin of rifling. The muzzle end heated up much more than the breech end.

Data is being collected and studies are being started of the effect of service upon the bore of cannon. Much more is known about nitrogen, hydrogen and carbon nowadays than before, and developments in allied fields are such that it appears that the hardening phenomenon might be duplicated in the laboratory. It is hoped that eventually it will be demonstrated what the white layer is, rather than what the white layer is not, from which many inferences are drawn.

X-RAY DIFFRACTION

Problems under investigation regard:

- 1st. Studies in diffusion of non-metallics in centrifugally cast gun steel; and
- 2nd. Studies in the distribution of stresses in gun tubes that are incident to processes of manufacture.

The preliminary surveys have been concerned with the first of the above problems. One preliminary problem was to discover whether or not X-ray crystal spectra can be used to identify solid non-metallics that occur as inclusions in the cast gun tubes.

The results indicate that the method has only limited promise if it has any promise at all, but further work will be needed before the method can be discarded entirely. That is, no identifications were obtained. The reasons for the failure seem to reside in the facts that many of the larger inclusions from which results were expected seem to be of the nature of glasses which are amorphous rather than crystalline. Since X-ray crystal spectra can be obtained only from crystalline substances, the method fails for such inclusions. Faint lines were obtained, however, which indicate that some inclusions are not glassy. These could not be measured because of the faintness of response of the photodensitometer which was used to measure the density of the lines and to determine their presence. This failure of the photodensitometer, a new piece

of equipment, was partly due to lack of proper adjustment, and partly due to coarse grain in the films or other film defects. Work is underway to get better grain in the films. Special development technique, worked out by Edwal laboratories in Chicago, and improved photodensitometric measurements will be tried in an attempt to measure these faint lines.

The second reason for failure of the method lies in the fact that fine inclusions are deposited apparently in sub-critical sized particles. These may or may not be crystalline in nature but there is a smallness of particle size below which crystal spectra cannot be obtained. Present evidence indicates that the deposited particles are of sub-critical dimensions.

The second preliminary study was an attempt to discover if, in fact, there is a variation of lattice parameter within the wall of the centrifugally cast gun. This work, carried out largely with equipment at M. I. T., was quite successful. There is, in fact, a variation of lattice parameter in the iron crystals amounting to approximately .03%. This difference seems to be positive and requires explanation. Explanations attempted in the preliminary survey seem to indicate that the difference cannot be ascribed to residual stresses nor to carbon in solution. It would appear that it is a function of diffusion of non-metallies. This effect will be studied quite intensively in the further prosecution of the problem.

Work in the problem of stress distribution is confined at present to calculations regarding effects to be expected. Experimental work will be undertaken as soon as the apparatus is available.

X-RAY RADIOGRAPHY

The important research in this field has been carried out in connection with X-Ray Specifications.

We are paying a premium on X-rayed castings. Part of this premium may be justified by the higher quality of product obtained; part of it, however, is due to the fact that producers have a confused idea or do not appreciate at all what is involved where X-ray specifications are applied. For instance, in an order for 19 cradle castings for 3" A. A. guns, about two years ago, 51 castings were tested to obtain the 19 required. The cost of testing the additional castings was such that the government in effect paid for two castings in order to obtain one. In addition the casting company not only made no profit, but lost heavily. It is considered that this condition of confusion should be eliminated. To this end there is needed a definite education of producers of X-rayed products, on the significance of X-ray tests.

The Arsenal has been in a position to further this education because of the fact that the A.S.T.M. is sponsoring a National Symposium on X-Ray Testing this year, and the chairmanship of the Radiographic Section of the Symposium has been assigned to Watertown Arsenal. Working through this A.S.T.M. connection, an attempt has been made to correlate present current thought with regard to specifications, to define in concrete terms the significance of X-ray tests, and to present to industry the crystallized thought and practice

with regard to X-ray tests. The work will continue through another year. The present work reaches a climax in the preliminary reports of the A.S.T.M. convention in Detroit in June, 1935. At this time, preliminary reports will be considered and plans made for the final reports to be made in June, 1936. These reports will consider all phases of radiographic testing. In particular, attention will be given to establishing definite policies with regard to radiographic tests which will eliminate confusion in the minds of producers and to establish definite criteria for the judgment of the quality of products that will be acceptable alike to producer and consumer.

To this end expressions of opinion have been asked from about 150 producers and consumers, including the Navy and Army Ordnance establishments. The final results will not be available, however, for another year. The results of the preliminary symposium will be communicated at an early date.

These results will consider such questions as:

1. What things should be specified?
2. Definitions of radiographic defects.
3. Interpretations of X-ray negatives.
4. Recommended forms for Specifications.

SPECTROSCOPY

During the fiscal year 1934-1935, the grating spectrograph completed in 1934 has had numerous valuable applications in qualitative and quantitative analysis. With the aid of this instrument, the analyst has been enabled to perform rapid preliminary identifications of unknown materials prior to wet quantitative analysis. This method of attack has been useful in the analysis of unknown ferro alloys, foreign armor plate, monels, etc., and particularly useful when the amount of sample available for analysis was very limited. Where qualitative analysis alone is sufficient, as in the case of metallic coatings and plates, spectrographic analysis has been rapid and positive.

In the field of direct quantitative analysis, the spectrograph has been employed here in two different methods of analysis - the internal standard and the comparison methods. The former is applicable where there is a series of steel alloys to be analyzed, the composition of which is constant except for the variation of one or more elements present to the extent of 1% or less, (for example, molybdenum in centrifugal casting steel). In such cases, it is assumed that the intensity of the respective iron spectrum lines will be constant from one steel to another under uniform conditions of spectral excitation and photography; but the intensity of the molybdenum lines will vary in accordance with the extent to which that element is present in the steel. Therefore, the intensity

ratio (determined by the photodensitometer) of any convenient, sensitive molybdenum line and a nearby iron line is a function of the molybdenum content of the steel.

Using this internal standard principle, Lt. J. W. Hansborough, in his thesis research, has attempted to establish calibration curves based upon a series of steel standards of known molybdenum content. Very accurate control of the analysis of the standards is necessary; further checking of the standards remains to be done. The same method can be extended to cover other alloying metals, such as nickel, chromium, vanadium, etc. Using similar methods, Lt. R. H. Coombs, in his thesis work, has investigated the diffusion of molybdenum in multiple pass butt welds of .50% molybdenum plate and plain carbon electrodes by spectrographic analysis of a condensed spark localized on the tips of pyramids cut .10" apart on the face of the weld cross-sections. He found that the concentration of molybdenum in the weld varies from layer to layer but is remarkably uniform in each layer.

A second method of spectrographic quantitative analysis is based upon the comparison of the spectrum of material under analysis with the spectra of synthetic standards containing known concentrations of added impurities. This method is applicable to the inspection of purchased material whose specification requires analysis for very minute traces of impurities. An approximate analysis of a very pure grade of

commercial zinc was made by visually comparing its spectrum with those of three synthetic standards consisting of chemically pure zinc with five different added impurities, the first containing twice the maximum allowable amount of the five impurities, the second containing exactly the maximum and the third containing one-half the maximum. Similarly, bouchon zinc base die castings were spectrographically analyzed for traces of cadmium and iron by the comparison method.

Another interesting application of the comparison method is in the determination of minute amounts of residual elements in gun steel, with the object in mind of correlating their presence with physical properties of the steel. Preliminary spectrographic work has indicated the presence of traces of tin in gun forging steels tested, and a series of synthetic standards of tin added to acid solutions of pure iron are now being established for its determination.

GUN FORGINGS

In the studies of forgings a connection was definitely established between macrostructure and heat treatment of the metal. The particular characteristics of well treated metal subjected to long normalization at higher temperatures were ascertained experimentally. They served as a guiding factor in developing and establishing heat treatment procedures for centrifugal castings for cannon; for various forgings; and with great success, for working out proper treatments by one of the manufacturers of gun forgings for 155 mm. cannon. With a new installation for macroetching, which permits the study and registration of time and temperature factors during etching, it is believed that practical results leading to the proper control of heat treatment and the possibility of distinguishing the quality of forgings or castings will be accomplished. That problem in its final and definite form, has not yet entered into the scope of the work, but preliminary material is accumulated in sufficient quantity and the method of attacking the problem, as well as its practical possibilities, are now clear.

The application of the macroetching method of inspection to the gun forgings for 105mm. A. A. guns and 155 mm. guns, procured during the year, afforded an excellent opportunity to test and develop the principles and conclusions found previously, when the method was applied to gun forgings of smaller caliber.

The practical usefulness of the method was finally established and confirmed in all stages of cannon manufacture. Particularly interesting is work, which cannot yet be considered as completed, on establishing the relation between the macrographic data obtained from the macroetching test and the defects that appear in the gun forgings as they pass through various stages of manufacture, particularly the cold working process and final machining operations. Determination of the connection between these defects and various factors in the manufacture of forgings was definitely established.

With a definitely worked out method of masks, determining the limits of useful metal constituting the gun body, it is a comparatively easy matter to make predictions regarding the success with which a forging can pass various stages of manufacture; it is also easy to predict the character of the fractures to be expected in physical testing and, to a certain extent, to predict relative values to be expected in that test. The causes of "laminated fracture", of "woody fracture", of "flake-like condition", of "white streaks", of sand-splits", of "crack-like formations" at the edges of forgings, of dark streaks appearing in the bore on cold working and on the surface of the guns after final machining, are, it is believed, well established by observations of the guns passing through laboratory control and manufacture at Watertown and Watervliet Arsenals. Preliminary work in that direction was done during previous years, but a final development of the method and decisive studies were made during the past year. It is under-

stood that further accumulation of observations and data will only strengthen the conclusions already made, and this is highly desirable in the interest of further progress in the manufacture of cannon.

Considerable time was devoted to a thorough study of a defect known as "flakes", which serves as one of the principal causes for the rejection of a very large number of forgings. Particular opportunity to study this question, highly important in the manufacture of cannon from forgings as well as from centrifugally cast metal, was afforded by the submission of materials and data by the Navy in connection with some Navy gun forgings. While experimental study of the question was not extensive, the study of practically all available literature (in English, French, German and Russian) was carried out. The experimental work done at the Krupp Works, beginning in 1905, well explains the bold use by the Germans of such steels for the manufacture of guns and for various ordnance requirements, which were avoided by other countries. The study definitely indicates the necessity of putting the heat treatment operation in gun forging manufacture on a highly scientific and up-to-date engineering basis, with proper attention to furnace equipment and technical personnel. Apparently, further developments in gun manufacture will be closely connected with these factors. It is interesting to note that apparently the methods of inspection of metal under procurement for cannon, as applied now at the Watertown Arsenal, give sufficient protection against

the unexpected appearance of defect flakes in various stages of manufacture and cause no belated rejections.

The macrographic studies of gun forgings were closely connected to studies of the same character on centrifugal castings for cannon as well as for experimental work used in developing this method of gun manufacture.

The correlation of chemical composition with the manner of crystallization and distribution of various zones of crystallization and distribution of various zones of crystallization resulted in the lowering of carbon content in the metal in order to obtain a more homogeneous structure and to exclude the presence of undesirable interdendritic voids forming the seat of defects leading to unsatisfactory fractures and irregularities in physical properties. In connection with experimental castings, the studies resulted in establishing the fact that with highly alloyed metal for centrifugally cast guns, it is necessary to consider better practice in cooling the metal immediately after casting and, in such further operations, where heating and cooling of the castings are involved. The appearance of flakes will follow any lack in proper procedure in such cases.

Considerable study of the material available from the manufacturing data of centrifugal castings, together with additional observations on castings and guns at various stages of manufacture, including systematic boroscopic examination of the bores before and after cold working, have led to establishing quite a definite theory on the process of freezing of the

metal in the centrifugal process. Particularly important is the part played by the formation of cold shuts of various magnitude: this connects definitely the success of castings with such factors as preheating of molds, proportioning of pouring rate, temperature of metal, etc. It is interesting that a certain parallelism was established in the defects of guns forged and guns cast centrifugally. Further macrographic studies of the whole subject are essential for the development of this method of manufacturing cannon, an especial point being the changes in structure caused by changes in profile of the molds and the effect of such changes on the properties of the castings. In that respect, considerable material for study was presented by the manufacture of 11 Navy guns carried out by the arsenal. Some definite conclusions were reached, but further observations are very essential for the continued success of the process. Careful study and consideration of the macrostructure of all castings is of great importance in designing molds for gun castings of small and large calibers, or for any hollow bodies, such as rolls, recuperator cylinders, etc. From the accumulation of such observations and their systematizing, it will be possible later to develop certain general principles important for practice.

The arsenal's experiments in making steels of various compositions for armor plate served as an excellent and rare opportunity to collect data on the effect of composition on the

mode of crystallization of the metal. This first-hand information, which showed the effect of such important elements as Chromium, Nickel, Molybdenum, when their content is brought to comparatively high values, represents a very valuable material for the development of such manufacturing processes as the centrifugal casting of guns and the development of the interpretation of macrographic inspection of metal. It is also believed that consideration of the macro structure of armor plate, in its various stages of manufacture, and correlation of the ballistic properties with those data may be of considerable value in developing desirable armor plate. Continuation of the work is thought necessary, especially since it deals with highly alloyed metal, which apparently has become a necessity in contemporary gun making, and about which there exists only very little informative literature.

Considerable interest was connected with the continuation of studies and correlation of various manufacturing data on gun forgings. This year, the necessary information from the manufacturer was obtained almost simultaneously with the submission of the test metal, and thus the opportunity was afforded to correlate properly the studies with observations on the guns during processing in the shops. Among other things, it appeared that gun forging specification requirements for reduction in cross-section during hot working are insufficient. The manufacturers never use as low a reduction as 2 to 1, but always a considerably higher value. Variations in the compo-

sition of the metal do not present any difference in average physical properties, the principal difference apparently lying in the effects on macrostructure; in the case of hot working, and the manufacturer's habit of using that composition. In this country, the variations in the method of manufacture (casting practice, forging, heat treatment and even sampling operations) are such that the manufacturers clearly demonstrate the lack of sufficient experience in making larger gun forgings. Apparently, the manufacturers often punish themselves in not considering in greater detail the process of manufacture and not having more suitable equipment (furnaces, presses, molds, etc.) for manufacture. This fact, of course, reflects on price and deliveries of the forgings, and also on the tendency of manufacturers to pass through unsatisfactory forgings. Substantial confirmation of these points was given by study of the materials in the Navy guns mentioned above. The principal cause of defects of so many forgings and all the trouble involved should be considered as the unsatisfactory technical treatment of the problem and lack of experience, and, therefore, knowledge of the subject.

Quite an important development was firmly established in the technique of study and inspection of guns during the past year. A series of preliminary observations and experiments clearly indicated the desirability and concrete possibility of applying the macroetching method to the investigation of the finished surface of the bore of the guns, without possible

injury to the rifling. This year a definite experiment was made on several guns at Watervliet Arsenal by the staff of this arsenal. Suitable plugs and a method of introduction of liquids were devised so that only a definite portion of the bore was affected. The necessary inspection and measurements were carried out by Watervliet Arsenal to prove that after such treatment the surfaces of the bore remained in satisfactory condition for service. It is believed that these experiments, confirming completely the previous studies, open a new way for practical experimental study of many questions connected with the design and manufacture of cannon. The above is especially true if the methods of boroscopic examinations and recording of results are brought to up-to-date standards.

Studies of metal for breechblock forgings, which are carried out in cooperation with Watervliet Arsenal on stock procured for actual manufacture, were continued with some definite results, important for immediate application. It was established by macroetching methods that consideration of the length of the stock, together with the macrographic picture, presented by two test metal slabs taken at the extreme ends of the stock, is an essential factor in selecting the stock. Definite data for a specification in that respect were obtained. It shows that the length of each bar under procurement should not be more than 6-8 feet under usual conditions of working. It further showed that reduction under the hammer is not desirable, and even when applied after reduction by a heavy press,

it was superfluous. Reductions under press give excellent results, when carried far enough to produce homogeneous macrostructure with practically all dendrites disappearing. A macroetching test, as now modified by Watertown Arsenal, together with production data furnished by the manufacturer at the time of submitting test metal (in accordance with a special questionnaire prepared by the Laboratory) allow not only an estimation of the suitability for the manufacture of breechblock metal, but also make possible the saving of a considerable part of the unsatisfactory stock by indicating the length to be discarded.

The method thus developed is already in operation (although further studies are continued when the opportunity presents itself) in order to establish more exactly the limits of variation from an ideal macrographic structure, and in this manner preparing certain margins for future necessity. This work is important for immediate application; it was found beneficial by the Watervliet Arsenal and attracted the interest of the Navy. By necessity it is slow, as the results are founded on actual manufacturing data, beginning with the procurement stage and ending with the final behavior of the breechblocks in service. This year, investigation included breechblocks for 105 mm. A. A. guns.

In order to expand the application of the macroetching method and to allow its substitution for less appropriate fracture tests, special experiments were made to carry out a macroetching test on ordinary surfaces produced by sawing off

the ends of pieces of metal. The results indicated complete applicability of the method in such cases. This fact deserves particular attention in connection with specifications for the procurement of stock for shells at any stage of its manufacture. A complete development of a definite method for this particular case will take very little time, in view of the material accumulated in previous studies. Much greater uniformity and reliability in quality of the material for shells will be obtained by the substitution of macroetching for fracture test.

MACROETCHING

The latest practise is to receive at the same time test discs are submitted the complete metallurgical history of the forging under consideration. In this manner the physical test and macrostructure are definitely correlated at once, and their causes determined. When values are not up to specification standards, suggestions are offered for improvement of the original material. The result has been that the manufacturers meet the time limit for delivery much better than in earlier years, and also fewer forgings are being made for any one order. Two companies made a total of 16 forgings for a delivery of 16, while one other company made only 15 forgings for a delivery of 12 forgings of large size.

Investigations were made for the Navy Department on defects found in recently finished gun tubes. It was observed that with the present Ordnance Department procedure, which includes macroetching, metal containing flakes would have been completely rejected for use by considering only the test metal shipped to this arsenal, while the body of the forging was still at the manufacturer's plant.

Routine inspection of purchase order material intended for severe service has broadened to include breechblock steel, tool steels, stainless steels, all types of monel metal and bronzes. The result has been that there is practically no rejection of defective material, and manufacturing schedules are more easily maintained.

Arsenal ingots and forgings were studied and their results correlated with purchased forgings in order to establish the effect of proper composition, amount of reduction, and proper macrostructure. The effect of various heat treatments including high temperature normalizing were shown to have a very definite part in changing the macrostructure to suitable and acceptable structures.

Forgings of large size with limited amount of reduction during hot working have been carefully studied. In this group, containers for cold working have shown a marked improvement over two years ago. The steel was forged better, had better heat treatment and macrostructure, and showed fewer areas of concentrated impurities than earlier submissions.

METALLOGRAPHIC STUDIES

Among the various metallographic studies conducted during the past year the following are typical.

Numerous specimens of armor piercing bullet core stock were examined prior to heat treatment to ascertain the quality of the metal. The steel was commercially clean but had a decidedly banded center. This banding would give directional properties and probably could not be removed in heat treatment. This banding was the result of rolling the ingot before it had become homogenized in the soaking pit at the steel mill. No surface decarburization was found in any of the specimens. This previous fault had been corrected.

Several years ago a high speed steel was developed at Watertown Arsenal using molybdenum in place of tungsten. One of the difficulties in heat treating this molybdenum high speed steel is that if heated in an uncontrolled atmosphere decarburization and demolybdenumization resulted to such a depth that too much grinding was necessary. However, if a suitably controlled furnace atmosphere or borax coating was used, this trouble was removed. This type of steel modified by the addition of a small amount of tungsten is now a commercial product sold under the name of "Mo-Tung." We are users of this steel in limited quantities and since the installation of the Hayes Certain-Curtain furnace, in which the furnace atmosphere can be controlled, we have experimented

to find the correct atmosphere for this type of steel and can now heat the steel so that no soft edges or surfaces result provided that the steel is of good quality.

Unfortunately we received one lot which failed or cracked badly in the machine shop. Investigation of the steel showed that it had been badly burned in heat treatment, but the steel was badly pined and segregated. This so changed the analysis that the melting point was lowered to the heat treating temperatures. Inasmuch as no macro-etch inspection had been previously made, the heat treating department did not know that the steel was bad. Several bars, that were in stock but not yet heat treated, were macroetched and all were found to be pined and segregated; they were withdrawn from stock. Recommendation was made that all tool steel bars should be macroetched on both ends as part of the acceptance inspection.

Monel metal castings have been studied with the view of grain refinement by heat treatment. Various heat treatments have been tried but so far little or no success has resulted. The regular monel metal is a solid solution and without marked transformation points. Such metals do not grain refine by thermal treatment in the absence of cold work. However, some of the above castings were not of the regular type but had additions of other elements and it was hoped to cause grain refinement by thermal means.

In the centrifugal castings at times are found numerous

cavities too small to cause rejection according to the physical property test, it was thought possible that auto-fretting might distort these cavities enough so that cracks would result. Several discs from cold worked centrifugal castings have been studied and so far no distortion has been noted. Therefore it is tentatively believed that if the cavities are not serious enough to cause rejection before cool work, they will not cause trouble after cold work.

Some fuse setter work that were pitted were taken out of service and sent in to ascertain the cause of pitting. The steel was of good quality and uniformly heat treated. In short, nothing was found to be wrong with the metal. It is suggested that improper cleaning after use or improper protection while in storage was the cause of pitting.

A sample from a lathe bed was submitted in conjunction with a bid for lathes received. The makers claimed that the "ways" had a deep "chill" and that this chill would greatly lengthen the life of the lathe bed. It was found that the "chill" did penetrate about 1" below the finished surface, but the "chill" only affected the grain and graphite size. As a matter of fact considerable malleabilization occurred just under the finished surface. This would cause soft spots along the ways instead of a hardened surface as claimed.

Physical Properties of Materials

Low and High Temperature Properties

In view of the use of Ordnance material under conditions involving extreme ranges of temperature, such as in guns and rifle barrels subjected to rapid fire, a program was instigated to determine the tension properties of the material compositions now used for such parts, throughout a range of temperatures from -110°F to $+1300^{\circ}\text{F}$. The data obtained conclusively emphasizes the necessity of giving greater consideration to the physical properties of materials at such temperatures as may be encountered in service, since many of the compositions now used show a decided falling off in tension strength as the temperature is increased. The results also indicate that material compositions other than those now used are definitely superior under the temperature conditions encountered. This investigation is being extended to include other possible useful compositions.

Impact

At the request of the Navy Department, Bureau of Construction and Repair, this laboratory developed a method of tension impact testing at low temperatures, which, when applied to special treatment heavy armor plate, is successful in picking out those plates which shatter when ballistically tested at low temperatures, such as below $+20^{\circ}\text{F}$. From the data obtained re-

quirements have been incorporated in the specification for this material, for tension impact test to be made from each plate at normal room temperature and -80°F . While the impact test does not indicate definitely the ballistic properties of the material it is expected that with the completion of the high speed impact testing machine now being constructed such properties can be readily determined.

Investigations of the subject of impact testing, during the past fiscal year, have clearly demonstrated the necessity of further study of the effects of impact velocity and form of specimen if the complete dynamic properties of materials are to be determined. It has been clearly shown that materials are sensitive to velocity changes, some extremely so, but that this effect is not definitely brought out under the present methods of impact testing. Studies of various forms of specimen notch have indicated the probability that the present standard form of specimen is not the most desirable for the purpose. Additional work is being done to clear up this undesirable situation.

The study of the subject of a relation between the static and dynamic tests has progressed to the point that it can be concluded that the mechanism of the process of deformation is essentially the same under both conditions, and that the dynamic properties of a material are dependent on three major factors: volume, velocity of the applied force, and material con-

dition. This study has also shown that to obtain a complete knowledge of the dynamic properties of materials, impact tests should be conducted through a range of velocities of a magnitude sufficient to definitely reveal material embrittlement.

This work has been extended to the testing of copper crusher gages, where preliminary tests indicate the possibility of developing a static test method whereby dynamic pressures can be correctly determined from the deformation produced.

Manganese Problem

(a) This Arsenal, the Ordnance Department, and the steel industry in general is faced with the problem of providing a substitute for manganese in steel-making practice. Over the past thirty years, an average of 17.4 pounds of metallic manganese has been used for each ton of steel made. In usual practice, this manganese is added in the form of ferro-manganese, an alloy made from manganese ores containing at least 45% Mn. Ores of this grade are relatively few in the United States. In recent years, several methods have been developed for the beneficiation of low-grade ore, of which there are many plentiful deposits in this country. Due to unfavorable economic conditions, but one of the various beneficiation processes has been operated successfully on a commercial basis. Therefore, the problem of immediate supplies of ferro-manganese in an emergency is still of serious consequence.

This arsenal has undertaken an experimental program which has as an objective the application of some substitute for manganese in the manufacture of steels in the high frequency induction furnace. It is quite possible that such a substitute, if found, may be equally applicable in the manufacture of open hearth and electric furnace steels. Possible substitutes for ferro-manganese are: (1) manganese alloys made from low-grade ores; i.e. spiegeleisen, silico-manganese, etc., (2) other deoxidants capable also of combining readily with

sulphur such as, zirconium, titanium, etc.

(b) Work done during the W. Y. 1934 indicated that, for oil-lined high frequency furnaces, silicon should be added about the time the charge is completely melted and manganese at some short time thereafter - probably about 1/3 of the entire time interval between the time of addition of the silicon and the time at which the heat is to be tapped.

By such procedure, it was possible to increase the tensile strength and proportional limit of the same steels about 15% and the Charpy tensile impact strength about 12 1/2%, without appreciable decrease in elongation or reduction of area. Steels made after the method indicated showed smaller primary grain size but were not as clean (microscopically) as were steels made with other deoxidation practices.

(c) During the current year studies of the grain-size relationship were made and it is now planned to carry forward those phases of the problem dealing with the use of substitutes for ferro-manganese.

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TINLESS SOLDERS

At the beginning of this year's program, some sixty alloys for soldering had been made and tested for tensile strength in shear on soldered lap joints on five different materials and thicknesses. Most of these alloys contained the eutectic ratio of lead to cadmium to which had been added small amounts (less than 10% of zinc, bismuth and tin both singly and in combination.

One of the properties that was considered especially desirable was resistance to impact or rough handling. A small Charpy impact machine was available and it was thought that the Charpy values would give a good indication whether or not the soldered lap joint could withstand rough handling.

Sixty alloys soldered to five different materials of two thicknesses seemed to be too large a number of tests at least to start with. Therefore it was decided to preliminarily select or eliminate some of the solders until a reasonable number of alloys were obtained for study.

One of the properties of a good solder is stability at soldering temperatures for a considerable time as in machine soldering. Oxidation tests on the solders were conducted by filling shallow dishes exposing a large surface with the solder of known weight and heating the solder to the soldering temperature and holding at temperature for a maximum of two days (48 hrs.) after freezing the solder was again weighed and the gain in weight due to oxidation was used in grading the stability of the solder. It

was found that in the sixty solders tested the solders that oxidized badly also had the lowest tension strength in shear (probably due to more or less oxide in the soldered joint.)

This oxidation test eliminated all the alloys containing tin, and most of the solders containing bismuth except those alloys containing zinc plus small amounts of bismuth. The solders containing tin were particularly bad about oxidizing as the oxide was granular and did not form a continuous film; in fact most of them were nearly 100% oxidized in half an hour, and the oxide expanded in a very porous granular manner which overflowed the containers and would have required a container many times the size used to hold it. It was found that it was the cadmium-tin combination that was responsible. The alloys containing zinc and bismuth form a continuous film rather quickly but once the film was formed it acted as a protecting film preventing further oxidation, or at best oxidation proceeding at a very much retarded rate.

Oxidation tests were conducted with the solders containing tin with the surface protected with melted zinc chloride. No oxidation resulted as long as the zinc chloride remained, but zinc chloride slowly volatilized and fumed. This showed that if the melted solder surface was protected from the air so oxidizes or dross would result with prolonged time. However, machine soldering conditions were not a part of this investigation and no further study of protection of molten solder was conducted.

The net result of the oxidation tests, coupled with the tensile strength of soldered lap joints was that about eight solders all containing zinc were selected for further study.

One difficulty in testing with the Charpy Impact machine was at once encountered. The results varied widely. On studying the ruptured tests it was noted that joints having high impact strengths had large fillets while those having low impact strengths had small fillets.

Study was conducted to determine the effect of fillets on both tensile and charpy results. The larger fillets had the greater strength in both tensile and impact values, but the Charpy impact was by far the most sensitive. A certain shaped fillet was adopted for subsequent work; better results were obtained. However, there are still too many variations and this requires many tests to get a reliable average.

Tests are still being conducted so that reliable averages can be obtained; it is expected that a sufficient number of tests will have been made by the end of this year so that a report can be drafted.

Specifications

During the past fiscal year there has been considerable activity in connection with the reviewing of proposed new and revised War Department and Federal specifications. This work covered both ferrous and non-ferrous materials in the form of rods, bars, plates, sheets, etc., forgings, and castings, etc., and also specifications for completed articles and equipment. Considerable time was spent in connection with Federal specification QQ-M-151 General Specification for Metals. Although this specification has been somewhat revised to bring it into conformity with existing commercial standards, such as ASTM and SAE, there is still room for improvement, especially as concerns testing terms and methods of procedure. There are several sections of this specification which are impractical of application and should therefore be thoroughly studied and subsequently farther revised.

Radical changes in SAE specifications of metals have recently been published. Submission of revision of corresponding army specifications will be made at an early date.

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A tentative revision of Parts I, II, and III of this pamphlet has been prepared for issue to the various establishments of the Department for criticism and suggestion. Details of specification have been brought up to date with those of the SAE and ASTM. Suggestions and criticisms from the several arsenals, particularly with reference to their applications and practices, must be included in this revision before it can be of maximum value. When they are received and have been incorporated, this revision will be ready for submission to the Chief of Ordnance. It is anticipated that Part IV, "Wrought Non-Ferrous Metals" will be similarly prepared in the near future.

ACTIVITIES WITH TECHNICAL SOCIETIES

Satisfactory forms of contacts are available with the following Technical Societies in the subjects listed by membership of the laboratory staff on technical committees:

American Society for Testing Materials: Committees A-1 on Steels, A-4 on Heat Treatment of Iron and Steel, A-5 on Corrosion of Iron and Steel, A-9 on Ferro Alloys, A-10 on Iron Chromium, Iron-Chromium-Nickel and Related Alloys, B-3 on Corrosion of Non-Ferrous Metals and Alloys, B-6 on Die Cast Metals and Alloys, E-1 on Methods of Testing, and the Joint Committee on Investigation of the Effect of Phosphorus and Sulphur in Steel.

American Welding Society: Committee on Fundamental Research.

American Institute of Mining and Metallurgical Engineers - Iron and Steel Division - Manufacture of Alloy Steel and Non-Destructive Testing.

Welding Research Committee of Engineering Foundation: Membership in Committee and of Sub-Committee on Research Projects. This insures contact with research activities of the American Welding Society.

Society of Automotive Engineers - Iron and Steel Division (through consultant).

The utilization of the contacts have been most unsatisfactory because of lack of funds for travel. If the Department is to secure practical results from activities of national technical organizations, association and direct consultation are essential. This involves travel expenses.

ORGANIZATION

Owing to the necessities of the Arsenal because of increased activities on production programs and in maintenance activities employing Emergency Relief labor, commissioned personnel have been relieved from duty in the Heat Treatment, Spectroscopy, and Armor Plate Sections of the Laboratory, and at the end of this month will be relieved from the Centrifugal Casting Section, leaving in the Laboratory only one commissioned officer, a small part of whose time is available in the Cold Work Section. During the year no commissioned personnel has been available for executive duties in the Laboratory. The position of Laboratory Director has been filled by the Commanding Officer in addition to his other duties. Unless commissioned personnel become available to a larger extent, a properly qualified civilian employee with research experience should be employed as Assistant Laboratory Director.

The civilian staff has been increased by a Metallurgist, who is being assigned to the Armor Plate Section and other activities involving ferrous alloys, other than non-corrosive alloys and gun alloys, and by an associate Metallurgist, now under training in the Foundry as a melter, who will be assigned research activities involving melting programs.

Additional professional personnel of the Junior Grade are badly needed in each of the following sections: Physical, Chemical, and Metallographic.

A proper utilization of experienced personnel on diffraction

and other physical work is not being secured because of lack of assistance in obtaining experimental data on current programs.

It is desired to assign an Assistant Chemist in charge of Spectroscopy and micro-chemical analysis. A junior chemist is badly needed for current analytical work in the Chemical laboratory.

Some metallographic work has been contracted for in outside laboratories. In spite of this, work is delayed because of inadequacy of the metallographic organization. Facilities are available and a junior metallographer should be added to the staff.

EQUIPMENT

During the year minor modifications have been made in buildings by Emergency Relief Labor to permit a better utilization of equipment. The spectrographic apparatus, plating equipment, and microscopes procured during the previous year have been put to limited use.

A Monohot Metallurgical microscope recently brought out by the Zeiss Company has been ordered but not yet delivered. It is a distinct improvement over microscopes now available. It makes available an objective of 1.6 numerical aperture.

A basement is being finished by Relief labor under the east half of the Chemical Building for use as a laboratory involving high temperature work. Space is being provided for a dilatometer, which it is hoped can be obtained at an early date, and for furnaces of laboratory type for heat treatment and other hot metal work. Forced ventilation in this laboratory and also in the plating room is being provided.

A high tension wire is being laid adjacent to the laboratory and a transformer is being installed. This will provide a source of current to the laboratories independent of the shop supply. To complete the installation a small motor-generator set or rectifier for providing direct current is still to be obtained. Considerable difficulty has been experienced owing to limited capacity and varying potential of electric circuits available.

Equipment for centrifugal casting and for high velocity impact testing will be referred to elsewhere.

Additional equipment is required especially for critical point determination, heat treatment, vacuum melting, micro-chemical analysis, fatigue testing, wear testing, and some forms of physical testing. It is also desired to take further advantage of recent developments in metallographic equipment. The need of more fully developed solidifying equipment is being felt.

LABORATORY REPORTS FISCAL YEAR 1935

- 111.2/5 The Testing of Metallic Materials With Particular Reference to the Tension and Impact Test.
- 130/1 Knowledge of Grinding and Polishing Operation.
- 145/1 Electromagnetic Method of Non-Destructive Testing.
- 314/457 Centrifugally Cast Stainless Iron for Recoil Mechanism Cylinders.
- 314/457-1 Stainless Iron Centrifugal Casting C-457 To Determine Reasons for Variations in Properties.
- 314/458 Development of Alloy Stainless Steels C-458
- 314/458-1 Stainless Centrifugal Casting C-458, Supplementary Report
- 315/2 Cracked Special Taper Reamer; "5" A. A. Navy Gun Mount Plunger Cylinder.
- 315.1/6 Molybdenum High Speed Tool Steel Cyclops Steel Co., P. O. 8893.
- 315.1/7 Failure of High Speed Tool Steels.
- 333.1/4 Investigation of Chilled Way on Lodge & Shipley Lathes.
- 344/22 K Monel Metal; Its Tensile Properties and Heat Treatment.
- 344/24 Wear Test of K Monel Metal - Part I Wiped Tin and Diffused Cadmium Coats.
- 344/24-1 Wear Test of K Monel - Part II. Effect of Tin, Solder, Cadmium, Silver Solder, Bronze and Various Lubricants.
- 344/26 Cold Working 18-8 Stainless Steel Bar by Longitudinal Stretching.

- 345/5 Macrographic Study of Silver Solder on Steel.
- 610/1 Notes on Forging Temperature and Smith Shop Practice.
- 613/127 A study of the Physico-Chemical Transformations in a Liquid Mass of Metal Cast Solid and Subjected to Centrifugal Force during Solidification of Centrifugal Castings.
- 635/12 Centrifugal Tube Castings C-464, C-482 and C483.
- 642/70 Butt Welds, 1/2" Structural Nickel Steel Plate.
- 642.1/27 81 mm Trench Mortar Base Plates, Examination of Weld Fractures.
- 642.3/1 High Current Automatic Welding Process, Single Pass Welding in Metal 3/4" Thick.
- 647/2 Repair of 5"/38 Cal. Navy A A Casting by Arc Welding (Bare Electrode) (K319-36).
- 647/3 Repair of 5"/38 Cal. Casting by Arc Welding (Covered Electrode) (K590-1 and K725-25).
- 649.1/3 Comparison of X-ray Tests of Spot Welds with Tests of the Same Welds made by Magnetic Analysis Corp., Long Island City, N. Y.
- 649.1/4 Comparison of X-Ray Tests with Magnetic Tests of Spot Welds.
- 671/1 Zinc Base Die Castings.
- 710/16 Light Armor Plate Abstract of Reports of Tests.
- 710/17 Light Armor Plate Summary Sheets, Abstracts of Report of Tests
- 710/20 Manufacture of Bullet-Resisting Ball Mount Castings for Medium Tanks, T3E2.
- 710/22 Report on Sprayed Face Armor Plate.
- 710/23 2nd Report of Tests of Composite Plates.
- 710/24 3rd Report of Tests on Composite Armor Plate.

710/26 2nd Report on Spot Weld Sectional Construction for Light Armor Plate.

710/27 Construction of the Armor Plate Test Range.

710/28 4th Report on Composite Plate C15 to C18, Use of Specially Hardened Front Plates.

710/29 5th Report on Composite Plate C19-C26, Change of Spaces and of Inner Materials.

710/30 6th Report on Composite Plates 1C-1 and 1C-2, The Use of Insulating Material.

710/32 1st Report on Grooved Steel Armor Plate, Tests of Grooved and Fluted Plates. Confidential Report

710/33 Armor Piercing Bullet Core Stock.

710/34 2nd Report of Test Spot Welded Joints on Armor Plate.

710/35 The Effect of Normalizing Armor Plate Ingots for Homogeneous Plate.

710/38 The Adaptability of the Gogan Brinell Hardness Testing Machine.

710/40 Armor Plate, 8-8-8 Alloy, Submitted by Republic Steel Castings, Inc., Reading, Pa. For Official Use Only.

710/42 Grooved Armor Plate - For Official Use Only.

730/3 Inspection of Bore Surfaces for Cold Work Defects.

731/4 Confidential Report - An Investigation of Erosion in Rocket Nozzle Throats Caused by Powder Gases at High Temperature and Velocity.

742/5 Corrosion of 3" A A Gun Mount M2 #5.

745/1 Report on Condition of Right Equilibrators from 3" A A Guns M1 #1 and #3, Ex.O. 76-A202-C3.

751/12 The Effect of Glycerine Solutions on Metals.

780/1 Partial Report on Galvanic Corrosion of Corrosion Resisting Steels.

810/5 Relation between Static and Dynamic Load-
Compression Properties of Copper Cylinders.

812/2 Tension Properties of Centrifugally Cast
Molybdenum-Vanadium Gun Steel at High and
Low Temperatures.

812/3 Tension Properties of Centrifugally Cast
Molybdenum-Vanadium Steel Used in the
Manufacture of 14.1 Guns for the Navy Dept.

Exp.

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The Use of Mn & Si in Steels Made in
Acid-Lined High Frequency Furnaces.

" 384

Study of Heat Treatment Practice Used
In Manufacturing Centrifugally Cast Cannon.